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Predicting response to fertilization using one-year changes in needle weight

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PREDICTING RESPONSE TO FERTILIZATION USING ONE-YEAR CHANGES IN NEEDLE WEIGHT

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INTRODUCTION

Nitrogen commonly limits the growth of temperate forest ecosystems (Keeney 1980). To offset nitrogen limitation of growth, forest managers have steadily increased the use of fertilizer nitrogen in the forests of the United States and Canada over the last two decades. Forest fertilization is an operational practice in coastal British Columbia, Washington, and Oregon (Bengtson 1979, Weetman and Fournier 1982). Nitrogen fertilization of selected sites can result in a substantial increase in merchantable volume and can increase profitability (Rennie 1957, Shoulder and McKee 1972, Miller and Fight 1979, Miller 1981, Steinbrenner 1981).

Study of the feasibility of nitrogen fertilization is underway in the northern Rocky Mountains of the United States through the efforts of the Intermountain Forest Tree Nutrition Cooperative (IFTNC). Fertilization trials are also being conducted in Interior British Columbia (Weetman and Fournier 1981, 1982). A central problem in determining the feasibility of fertilization is that establishment of long-term (5-20 yr) field trials is the most reliable method for predicting response to fertilization (Morrison 1974). A further complication is that response to fertilization in the heterogeneous and often droughty environments of the northern Intermountain Region appears to be quite variable (Scanlin and Loewenstein 1979, Weetman and Fournier 1982). The ultimate objective of the research we report here was to test a technique that enables prediction of response to fertilization one year after fertilizer is applied.

THE FERTILIZER SCREENING PROCEDURE

Krauss (1965) developed a simple graphical technique to predict nutrient deficiencies in Germany that has subsequently been applied in North America (Weetman 1979, Weetman and Algar 1974, Timmer and Stone 1978, Weetman and Fournier 1981, 1982). The underlying assumption is that, for coniferous species with determinate growth patterns, changes in needle weight and tissue nutrient concentrations the first year after fertilization will be well correlated with subsequent long-term growth (volume) response. Several studies do indeed document a high correlation between first season needle dry weight and subsequent growth response (Leyton 1957, Keay et al. 1968, Brix and Ebell 1969, Ebell 1972, Weetman and Algar 1974, Timmer and Stone 1978, Camire and Bernier 1981).

STUDY AREA AND FERTILIZER INSTALLATIONS

Within each installation (stand) a series of six 1/10th acre square or rectangular plots were established during the summer of 1981. Square plots were utilized when practical to reduce the amount of plot "edge." A treated buffer of at least 25 feet was included for each plot. The plots were as similar to one another in terrain, vegetation and stocking as possible, and each plot contained at least 10 Douglas-fir trees. Two controls and two replicated treatments were assigned to the plots at random, the treatments consisting of: 1) one application of 200 lb/acre actual nitrogen, and 2) one application of 400 lb/acre actual nitrogen. The fertilizer, in the form of urea, was applied during the fall of 1981.

Fourty-one of 45 fertilizer installations established in 1981 were sampled for this study during the fall of 1982. The fertilizer trials cover a relatively wide geographic and environmental distribution (Figure 1). Sample installations range from 32 to 100 years of age, 6.3 to 14.7" mean DBH, and 48 to 191 ft /acre mean basal area (Table 1). Many of the installations were thinned at least 10 years ago.

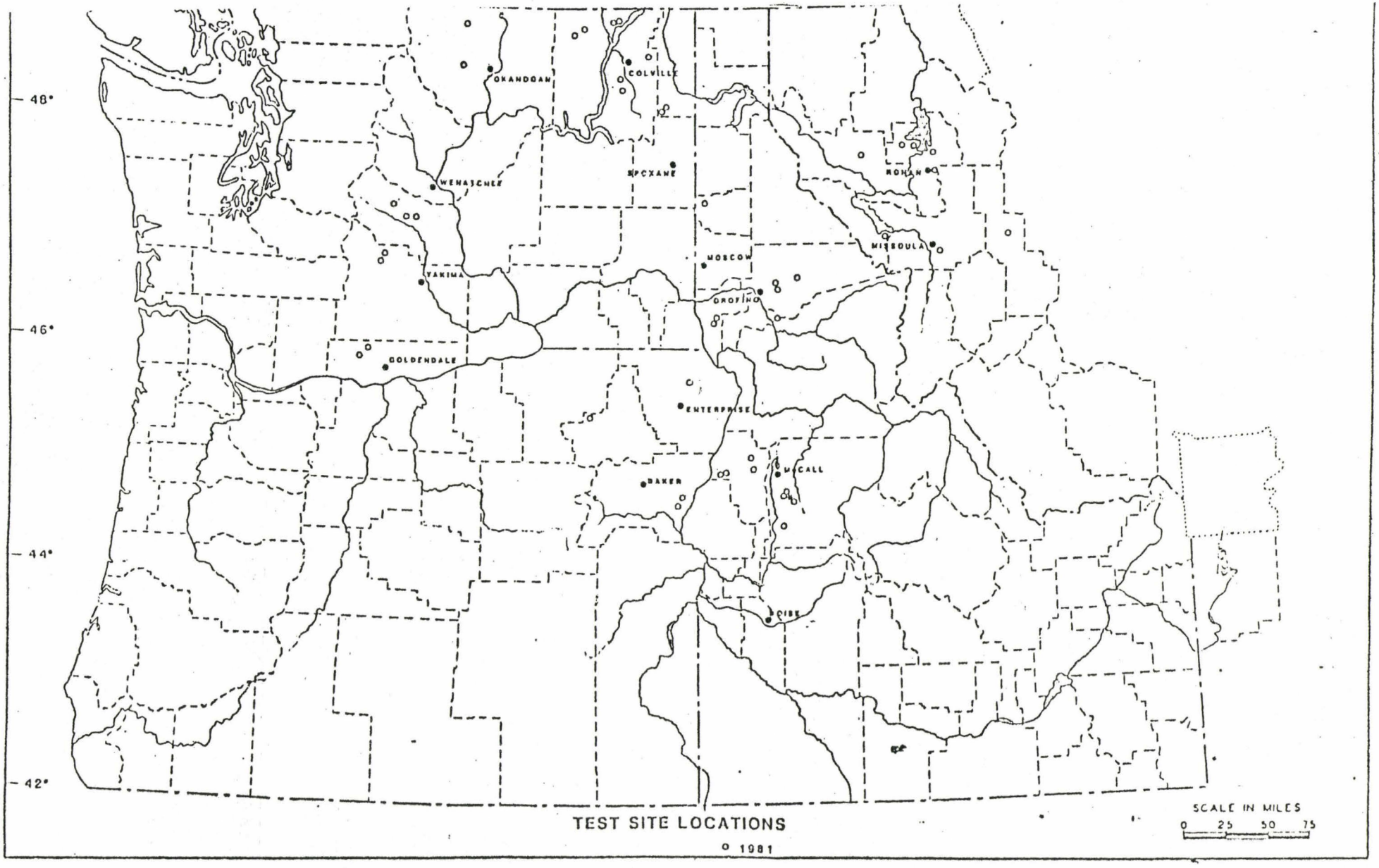


Figure 1. Location of the 45 IFTNC Douglas-fir fertilizer trials established in 1981.

Table 1. Stand and site attributes of the 41 fertilizer trials sampled.

Installation	Physiographic Region	Trees per Acre	Average DBH (inches)	BA/Acre (ft^2)	Stand Age	Site Index
201-Laffinwell Cr. #1	Central Idaho	228	9.32	113.6	59	54
202-Horsethief Basin	Central Idaho	182	8.05	66.9	58	45
203-Laffinwell Cr. #2	Central Idaho	162	10.31	99.9	69	51
204-Johnson Mill #1	N. Idaho	238	8.79	104.7	41	71
205-Johnson Mill #2	N. Idaho	227	9.24	110.6	41	75
206-Caribel #2	N. Idaho	260	9.92	152.1	46	75
207-Waha	N. Idaho	277	9.95	157.6	55	65
208-Lovell Valley Road	N. Idaho	150	14.63	188.7	88	72
209-Addy	N. E. Washington	182	11.78	143.2	68	67
210-Buck Cr.	N. E. Washington	272	9.38	143.7	54	62
211-Heel Cr.	N. E. Washington	472	7.70	171.9	34	77
212-Swamp Cr.	N. E. Oregon	197	8.47	81.4	71	50
216-Shmidt Mdw.	N. E. Washington	280	9.45	142.9	66	62
217-Emanual Cr.	N. E. Washington	218	9.47	113.4	75	56
218-Second Cr.	N. E. Washington	152	10.49	94.2	100	50
219-Little Salmon Cr.	Central Idaho	242	9.54	127.4	67	50
220-Grouse Cr.	Central Idaho	267	8.12	104.0	89	48
221-Little Mud Cr. #1	Central Idaho	180	10.48	118.1	82	52
222-West Mill Cr. #1	Central Idaho	355	8.09	138.1	71	47
223-West Mill Cr. #2	Central Idaho	225	9.06	111.3	75	50
225-Bowman Cr.	Central Washington	160	10.88	109.6	82	52
226-Cleman Mt.	Central Washington	132	10.81	88.1	79	48
227-Johnson Canyon	Central Washington	123	12.15	101.6	80	55
228-Lookout Mtn. West	Central Washington	212	10.70	140.4	64	71
229-Lookout Mtn. East	Central Washington	113	14.32	130.0	69	74
230-M. F. Teanaway R.	Central Washington	121	13.02	125.8	81	66
231-Elmo	Montana	168	10.00	97.0	61	57
232-Sunnyslope	Montana	197	11.11	137.7	54	69
233-Hellroaring Cr.	Montana	173	12.24	145.1	54	68
234-Ronan	Montana	177	11.47	131.5	59	63
235-Fish Cr.	Montana	325	7.64	110.4	74	48
236-Deer Cr.	Montana	298	9.72	168.5	80	55
237-Mollet Park	Montana	232	10.18	148.5	90	60
238-Buffalo Bill Cr.	Montana	213	6.25	48.2	32	58
239-Waha #2	N. Idaho	151	13.87	182.5	87	73
240-Quartz Cr.	N. Idaho	345	8.65	149.7	41	75
241-Woody Mtn.	Central Washington	303	8.00	112.3	72	53
242-N. F. Ninemile Cr.	Central Washington	430	7.12	139.0	87	49
243-Starvation Lake	N. E. Washington	240	9.67	129.8	73	58
244-Big Lookout Mtn. #1	N. E. Oregon	207	14.67	272.2	90	65
245-Big Lookout Mtn. #2	N. E. Oregon	250	11.04	191.4	52	53

METHODS

Foliage samples were collected from two trees within each plot (or from the fertilized buffer zone) for a total of 12 per installation. Trees were primarily of dominant crown class and were selected based on characteristics of good form, high vigor, and relative freedom from insect or disease problems.

The foliage samples were collected by climbing the trees with climbing spurs and belt; then, hand pruners were used to clip off current year shoots from the third whorl from the top of the tree. Special care was taken to collect determinate lateral shoots.[1]/ The samples were collected in plastic bags and stored in insulated coolers with ice while in the field. In the laboratory, samples were stored at -18°C until they were dried.

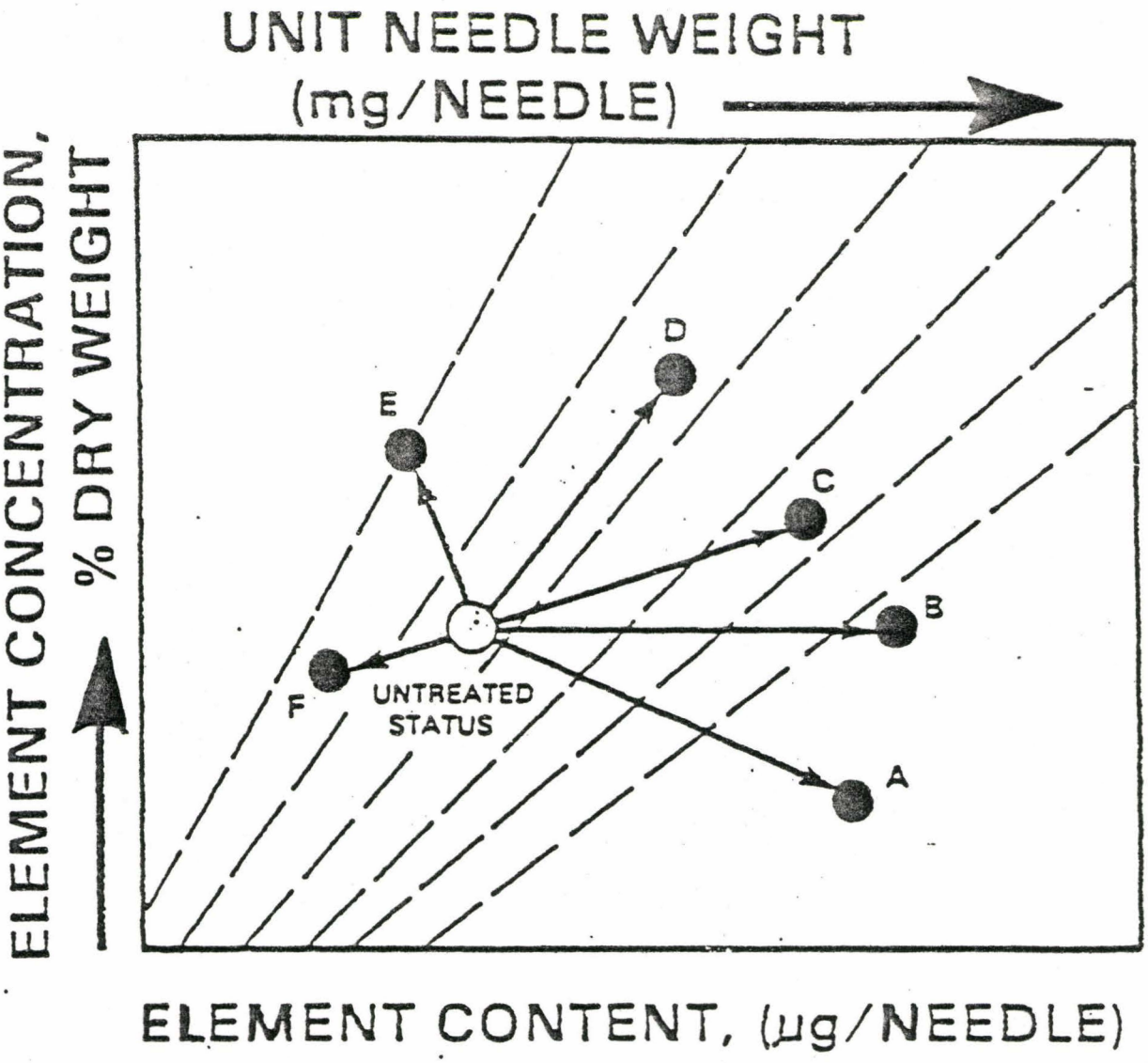
Shoots were oven-dried at 70°C for 24 hours and the needles were then separated from the twigs. Five replications of 100 needles were counted for each tree. Counted needles were then redried at 70°C for 24 hours and weighed. Mean needle weight was expressed as the average weight in grams per 100 needles. The coefficient of variation for the 5 replicates per tree was almost always less than 4%.

1/ Variation in branch and shoot morphology represents an unknown source of variation in needle size. We tried to standardize collection of shoots from the same relative branch position, avoiding the more indeterminate and variable terminal shoots.

To determine foliar nitrogen concentration a standard micro-Kjeldahl procedure was utilized (Bremner and Mulvaney 1982). Needles were ground with a Wiley Mill, digested with sulphuric acid, and the digestute distilled with steam. Total nitrogen concentration was reported as a percentage per unit of dry (70°C) needle weight.

The interpretation of changes in needle weight, nitrogen concentration, and nitrogen content used the graphical technique employed by Krauss (1965), Heinsdorf (1967), Weetman (1971), Weetman and Algar (1974), and Weetman and Fournier (1982). Timmer and Stone (1978) have derived the interpretations of the treatment shifts (Figure 2).

Evidence for response was based on three parameters. Within each installation the magnitude and statistical significance of changes in needle weight were examined. Secondly, the frequency was noted of trees exhibiting increased needle weights due to treatment. Finally, the graphical analysis (Figure 2) was examined. Based on the above evidence the installations were classed as: 1) no predicted response; 2) predicted response; and 3) variable and undecieded response. The variable and undecieded response category includes the following situations: 1) apparent blocked response where certain plots respond and others do not; 2) certain trees seem to respond while others do not; and 3) weak response. Virtually all trees within installations classified as predicted responders exhibit a strong and statistically significant change in needle weight across replications and treatments.



DIRECTION OF SHIFT	RESPONSE IN			CHANGE IN	
	NEEDLE WEIGHT	NUTRIENT		NUTRIENT STATUS	POSSIBLE DIAGNOSIS
		CONC.	CONTENT		
A	+	−	+	DILUTION	NON—LIMITING
B	+	0	+	UNCHANGED	NON—LIMITING
C	+	+	+	DEFICIENCY	LIMITING
D	0	+	+	LUXURY CONSUMPTION	NON—TOXIC
E	−	++	±	EXCESS	TOXIC
F	−	−	−	EXCESS	ANTAGONISTIC

Figure 2. Schematic relationships between nutrient concentration, nutrient content and dry weight of needles following fertilization (adapted from Timmer and Stone, 1978). (from Morrow, 1979)

RESULTS

Most of the trees fertilized exhibited increased levels of foliar nitrogen after one growing season (Table 2). Levels of foliar nitrogen were generally greatest within the 400 lbs/acre treatment. The correlation of levels of foliar nitrogen and amount of fertilizer implies that the study trees metabolized at least some of the fertilizer in proportion to application rate.

Needle weight response to nitrogen fertilization was highly variable. Needle weights from treatment plots ranged from -44% to +66% when compared to control plots (Table 3). Fertilization significantly increased weight in the first growing season in about 36% of the 41 fertilizer trials. Although trees fertilized at 400 lbs/acre did usually exhibit the highest foliar nitrogen concentrations (Table 2), these trees did not always show the greatest increase in needle weight. The additional nitrogen, therefore, was not always converted into proportionally greater foliage biomass. An important result is that, given the assumption there is a correlation between needle weight one year after fertilization and subsequent long-term growth (volume) response, nitrogen does appear to limit growth in at least one-third of the experimental trials.

Figures 3 and 4 depict the graphical analysis of non-responding and responding nitrogen fertilizer trials, respectively. Based on the graphical analysis of all 41 fertilizer trials, and other parameters (see methods), the Installations were classified as follows:

Table 2. Mean (standard deviation) foliar nitrogen concentrations one year after fertilization.

Installation	Nitrogen Concentration (%)		
	Control	200 lbs/acre	400 lbs/acre
201	0.90 (.18)	1.16 (.13)	1.46 (.21)
202	0.89 (.15)	1.02 (.05)	1.42 (.14)
203	0.98 (.04)	1.21 (.20)	1.36 (.16)
204	1.01 (.14)	1.28 (.22)	1.60 (.45)
205	1.12 (.17)	1.34 (.16)	1.66 (.52)
206	1.18 (.12)	1.35 (.02)	2.11 (.63)
207	1.08 (.06)	1.32 (.08)	1.57 (.26)
208	0.89 (.06)	1.06 (.04)	1.14 (.08)
209	1.16 (.07)	1.62 (.23)	1.37 (.21)
210	1.05 (.09)	1.38 (.15)	1.98 (.27)
211	1.13 (.15)	1.28 (.15)	1.73 (.37)
212	1.01 (.07)	1.17 (.14)	1.37 (.08)
216	1.05 (.22)	1.18 (.08)	1.29 (.11)
217	1.02 (.11)	1.52 (.28)	1.50 (.19)
218	0.90 (.02)	1.11 (.13)	1.36 (.02)
219	0.99 (.06)	1.23 (.15)	1.42 (.12)
220	0.88 (.10)	1.13 (.07)	1.37 (.12)
221	0.89 (.11)	1.37 (.23)	1.71 (.19)
222	1.01 (.05)	1.16 (.11)	1.32 (.05)
223	0.89 (.21)	1.26 (.25)	1.53 (.11)
225	1.08 (.15)	1.19 (.10)	1.76 (.20)
226	1.10 (.12)	1.18 (.17)	1.36 (.19)
227	1.04 (.17)	1.18 (.11)	1.19 (.06)
228	1.18 (.15)	1.36 (.19)	1.78 (.33)
229	1.11 (.09)	1.35 (.16)	1.81 (.30)
230	1.04 (.16)	1.10 (.11)	1.62 (.46)
231	1.08 (.08)	1.24 (.18)	1.49 (.24)
232	1.02 (.03)	1.35 (.20)	1.72 (.36)
233	1.09 (.08)	1.22 (.11)	1.86 (.46)
234	1.25 (.14)	1.41 (.11)	2.29 (.29)
235	0.94 (.04)	1.20 (.17)	1.76 (.22)
236	1.14 (.07)	1.21 (.12)	1.62 (.15)
237	1.11 (.08)	1.21 (.07)	1.24 (.26)
238	1.00 (.08)	1.32 (.16)	1.80 (.25)
239	1.00 (.07)	1.12 (.05)	1.58 (.40)
240	1.00 (.12)	1.21 (.06)	1.55 (.30)
241	0.88 (.03)	1.29 (.13)	1.41 (.23)
242	0.89 (.05)	1.11 (.06)	1.53 (.51)
243	1.05 (.06)	1.36 (.18)	1.47 (.38)
244	1.00 (.15)	1.01 (.14)	1.14 (.06)
245	1.05 (.05)	1.16 (.15)	1.40 (.29)
	1.02 (.10)	1.24 (.13)	1.55 (.25)

Table 3. Mean (standard deviation) needle weight and percentage change in needle weight for 41 fertilizer trials located throughout the Inland Empire.

Installation	Needle Weight (g/100 needles)			Percentage Change From Control	
	Control	200 lbs/ac	400 lbs/ac	200 lbs/ac	400 lbs/ac
201	.7004 (.1588)	.6843 (.0781)	.8617 (.1807)	-2 (NS)[a]	23 (NS)[a]
202	.5689 (.0955)	.7093 (.1617)	.6685 (.0692)	25 (.2)[b]	18 (.15)
203	.6761 (.1113)	.7394 (.1193)	.7035 (.1248)	9 (NS)	4 (NS)
204	.5590 (.0901)	.7149 (.0707)	.5804 (.1145)	28 (.05)	4 (NS)
205	.6872 (.1154)	.6735 (.0759)	.6157 (.0734)	-2 (NS)	-10 (NS)
206	.6480 (.0798)	.6337 (.0903)	.7093 (.1034)	-2 (NS)	9 (NS)
207	.5902 (.1282)	.5074 (.0716)	.6432 (.2740)	-14 (NS)	9 (NS)
208	.4257 (.1285)	.4639 (.0222)	.5391 (.0798)	9 (NS)	27 (.15)
209	.5223 (.1573)	.8613 (.1199)	.7408 (.0264)	65 (.02)	42 (.05)
210	.5101 (.0693)	.7105 (.1676)	.6700 (.0528)	39 (.1)	31 (.02)
211	.6566 (.1260)	.9065 (.1092)	.8557 (.0747)	38 (.05)	30 (.05)
212	.5931 (.1330)	.7040 (.1165)	.6730 (.0734)	19 (NS)	13 (NS)
216	.7731 (.1074)	.8085 (.1455)	.7765 (.0868)	5 (NS)	0 (NS)
217	.6556 (.1939)	.6958 (.0736)	.6686 (.0698)	6 (NS)	2 (NS)
218	.5783 (.0291)	.6324 (.1100)	.6673 (.1369)	9 (NS)	15 (NS)
219	.5240 (.0306)	.6101 (.0934)	.7298 (.2044)	16 (.15)	39 (.1)[b]
220	.6422 (.0714)	.6070 (.0919)	.8418 (.2029)	-5 (NS)	31 (.15)
221	.3845 (.0670)	.6225 (.0757)	.5887 (.1195)	62 (.01)	53 (.05)
222	.6483 (.2632)	.5563 (.1674)	.7482 (.0774)	-44 (NS)	15 (NS)
223	.6796 (.2130)	.7574 (.2323)	.8676 (.0952)	11 (NS)[b]	28 (.15)
225	.5640 (.0387)	.5366 (.1679)	.6579 (.1728)	-5 (NS)	17 (NS)
226	.5216 (.0547)	.6355 (.1215)	.7945 (.0689)	22 (.15)	48 (.001)
227	.7362 (.0673)	.6963 (.0880)	.7678 (.1850)	-5 (NS)	4 (NS)
228	.5648 (.0750)	.7471 (.1633)	.8179 (.1141)	32 (.1)	45 (.01)
229	.5380 (.1636)	.7065 (.1921)	.6809 (.1030)	31 (NS)	23 (NS)
230	.5926 (.1638)	.6290 (.1252)	.6614 (.1646)	6 (NS)	12 (NS)
231	.4427 (.0521)	.6986 (.2096)	.7327 (.2548)	58 (.1)	66 (.1)
232	.6356 (.1434)	.6586 (.0956)	.6114 (.1608)	4 (NS)	-4 (NS)
233	.5416 (.1302)	.6391 (.0827)	.5636 (.1350)	18 (NS)	4 (NS)
234	.6162 (.1831)	.7180 (.0495)	.5941 (.1350)	17 (NS)[b]	-4 (NS)
235	.5456 (.0857)	.6711 (.1860)	.7597 (.0533)	23 (NS)	39 (.01)
236	.5769 (.0533)	.6368 (.0784)	.7105 (.1295)	10 (NS)	23 (.1)
237	.3810 (.0450)	.5650 (.1312)	.5492 (.1410)	48 (.05)	44 (.1)
238	.7255 (.1540)	.9180 (.2003)	.8129 (.1102)	27 (.2)	12 (NS)
239	.4743 (.0974)	.5354 (.1978)	.6715 (.3090)	13 (NS)	42 (NS)
240	.5157 (.1304)	.7534 (.1413)	.6091 (.1892)	46 (.05)	18 (NS)
241	.6786 (.1090)	.6887 (.1846)	.7239 (.1046)	1 (NS)	7 (NS)
242	.4722 (.0950)	.5202 (.0747)	.5778 (.1018)	10 (NS)	22 (.2)
243	.6277 (.0715)	.7322 (.0604)	.7361 (.1399)	17 (.1)	17 (NS)
244	.6177 (.2507)	.5375 (.1316)	.6705 (.1448)	-12 (NS)	9 (NS)
245	.7485 (.1799)	.6390 (.1759)	.7691 (.1538)	-14 (NS)	3 (NS)
	.5888 (.0954)	.6698 (.1003)	.6981 (.0891)	+15	+20

[a] Probability that the treatment mean needle weights are significantly different than the control mean needle weights based on the t Statistic for two means (NS = not significant). Observations pooled across replicate plots.

[b] Plots are blocked along environmental gradients in the field; one plot exhibits a significant increase in needle weight (t statistic) while the other does not.

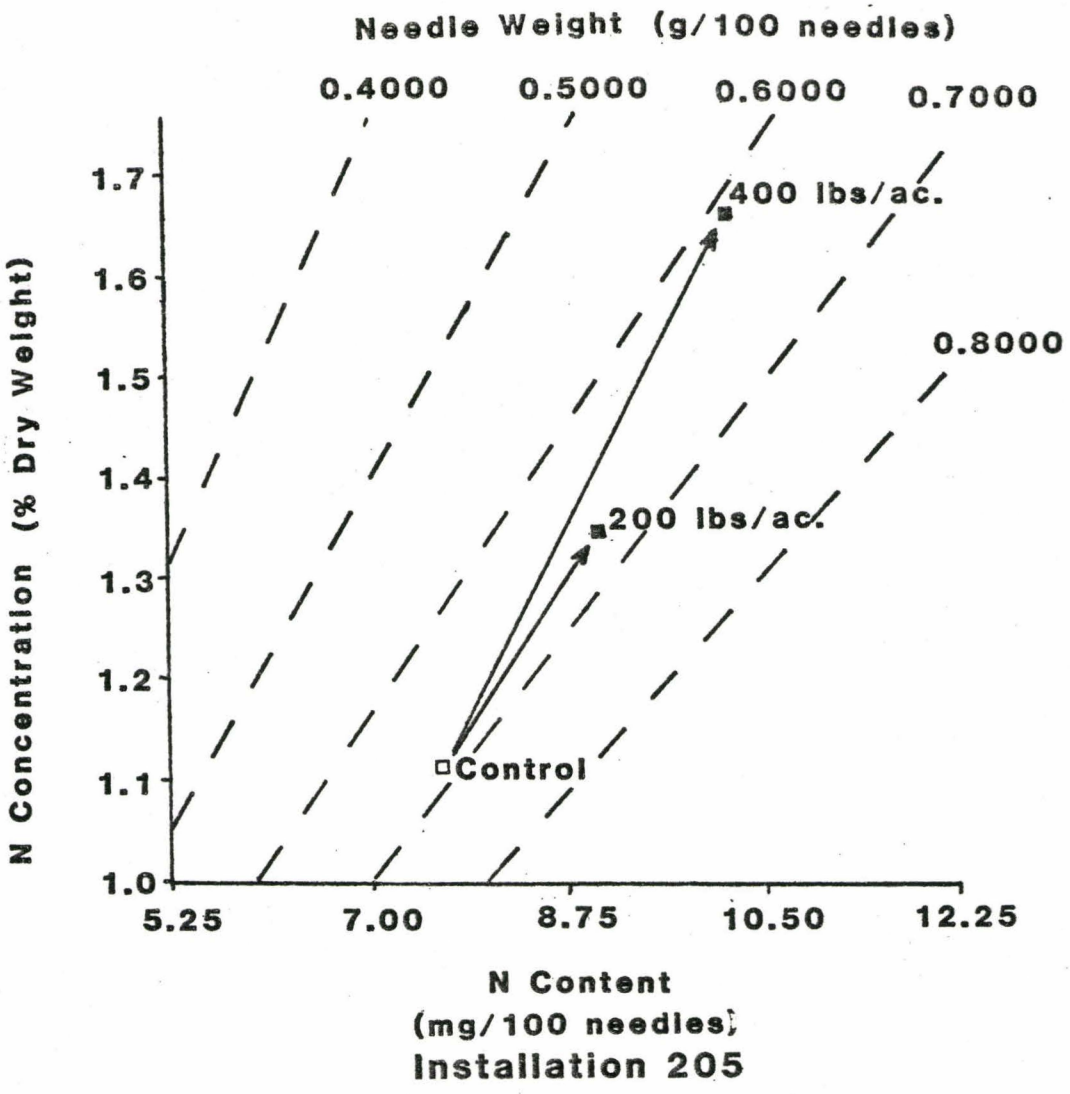


Figure 3. Relationship among needle weight, nitrogen concentration, and nitrogen content for IFTNC Installation 205. An increase in stem growth is not expected based on the graphical analysis.

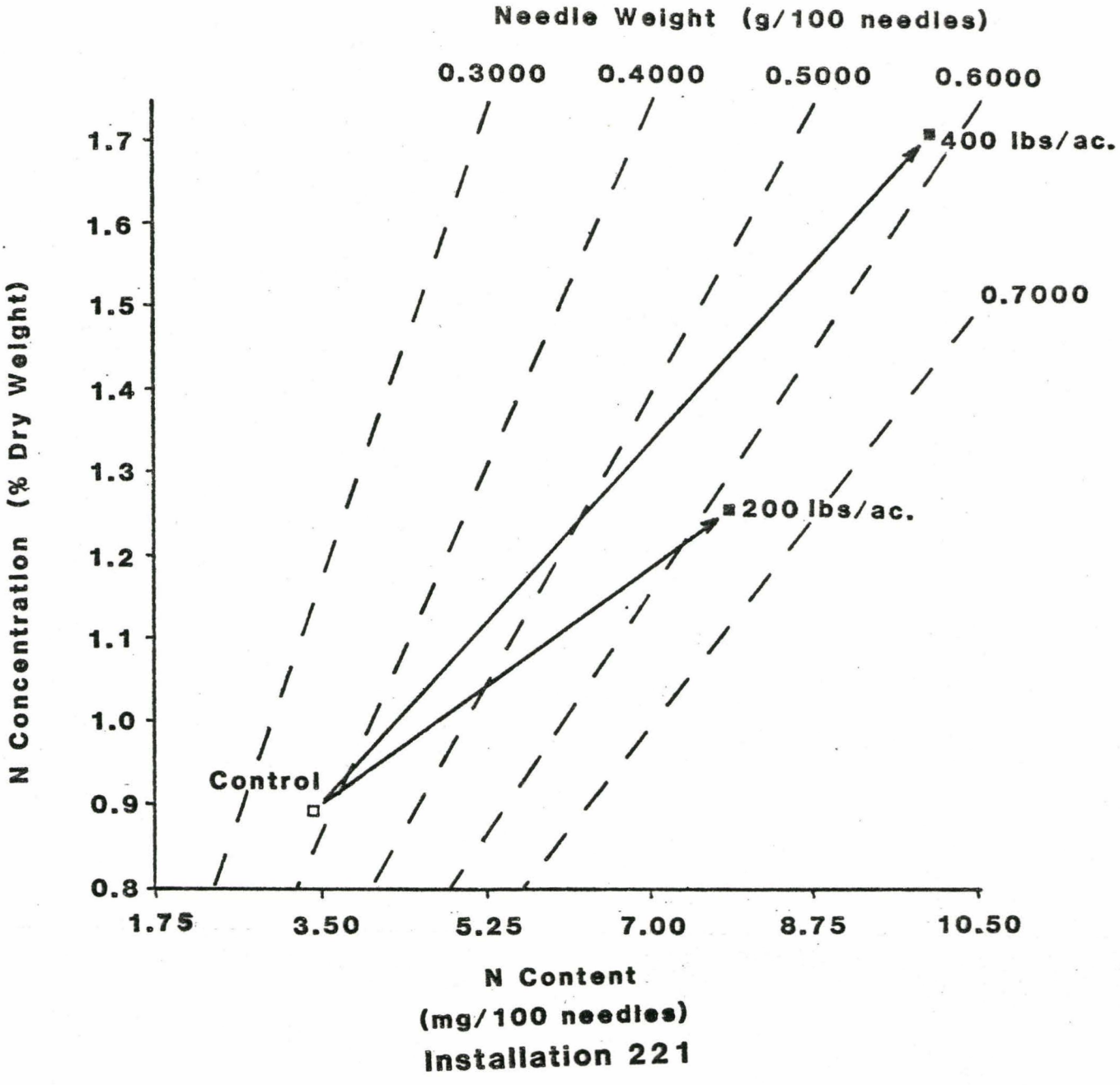


Figure 4. Relationship among needle weight, nitrogen concentration, and nitrogen content for IFTNC Installation 221. An increase in stem growth is expected based on the graphical analysis.

Response Category	Number of Installations	Percentage of Total
1. Nonresponders (Table 4)	10	25%
2. Clear and Strong Response Across All Treatments (Table 5)	10	25%
3. Blocked (Table 6), Variable, and Weak Response	21	50%
	41	100%

The third response category included all installations exhibiting blocked response (response vs. no response for replicate treatment plots), and weak or variable response (only certain trees appear to respond).

Based on the "Krauss" or Weetman" graphical analysis we predicted at least 25% of the fertilizer trials to show a strong growth response. An additional 10-25% of the trials will probably exhibit a positive growth response, the magnitude of which will not be clear until actual growth is correlated with predicted response.

Table 4. Fertilizer installations predicted to be nonresponsive to nitrogen fertilization.

Installation #	Geographic Region	Stand Age (years)	Basal Area (ft^2/ac)	Site Index (feet)
205	N. Idaho	41	111	75
216	N.E. Washington	66	143	62
217	N.E. Washington	75	113	56
227	Central Washington	82	101	55
230	Central Washington	81	126	66
232	Montana	54	138	69
241	Central Washington	72	112	53
242	Central Washington	87	139	49
244	N.E. Oregon	90	272	65
245	N.E. Oregon	52	191	53

Table 5. Fertilizer installations predicted to respond strongly to nitrogen fertilization.

Installation #	Geographic Region	Stand Age (years)	Basal Area ft^2/ac	Site Index (feet)
209	N.E. Washington	68	143	67
210	N.E. Washington	54	143	62
211	N.E. Washington	34	171	77
219	Central Idaho	67	127	50
221	Central Idaho	82	118	52
226	Central Washington	79	88	48
228	Central Washington	64	140	71
231	Montana	61	97	57
235	Montana	74	110	48
237	Montana	90	149	60

Table 6. Fertilizer installations of blocked, variable, and weak predicted response to nitrogen fertization.

APPARENT BLOCKED RESPONSE

Installation No.	Geographic Region	Response 200 Lbs	400 Lbs
201	Central Idaho	No Response	Plot 2 - Response Plot 4 - No Response
202	Central Idaho	Plot 3 - No Response Plot 5 - Strong Response	Plot 1 - No Response Plot 4 - Response
203	Central Idaho	Plot 1 - Response Plot 6 - No Response	Plot 2 - No Response Plot 5 - Response
204	N. Idaho	Response	No Response
206	N. Idaho	No Response	Plot 3 - Response Plot 4 - Undecided
218	N. E. Washington	Plot 2 - No Response Plot 4 - Response	Plot 1 - No Response Plot 5 - Response
220	Central Idaho	No Response	Strong Response
229	Central Washington	Plot 6 - Response Plot 3 - Undecided	Undecided Probable Response
236	Montana	Undecided	Response
238	Montana	Undecided	Plot 3 - Undecided Plot 4 - Response
240	N. Idaho	Response	Undecided (Variable)

VARIABLE AND WEAK RESPONSE

Installation No.	Geographic Region	Comments
207	N. Idaho	Nonresponder except for one tree?
208	N. Idaho	200 lbs. - no apparent response 400 lbs. - smaller trees responding?
212	N. E. Oregon	Weak response?
222	Central Idaho	Variable response
223	Central Idaho	400 lbs. - plot 6 response, other single trees responding?
225	Central Washington	Single trees responding?
233	Montana	No response?
234	Montana	200 lbs. - plot 2 responding
239	N. Idaho	400 lbs. - single trees responding
243	N. E. Washington	Weak and variable response?

DISCUSSION

Weetman and Fournier (1982) reported lodgepole pine first-year mean fasicle weight increases of about 20% for three levels of nitrogen fertilization (range +8 to +60%) for 16 stands in interior British Columbia, suggesting a strong probability of appreciable 5-year volume increase. The average increase in needle weight for the 41 stands of this study was 15% at 200 lbs N/ac and 20% at 400 lbs N/ac, but change in needle weight was highly variable (Table 3).

Camire and Bernier (1981) found a 20%, five-year volume increase following a 50% increase in needle weight for a jack pine stand with ammonium nitrate applications at 224 Kg N/ha. For the same species larger five-year volume increases were associated with 40% increases in needle weight in an Interprovincial Canadian Forest Fertilization Trial, also with an application rate of 224 Kg N/ha (Krause et al. 1982, Weetman and Algar 1974). The 10 installations classified as strong responders in our study had average increases in needle weight of 40% at 200 lbs N/acre and 44% at 400 lbs N/acre. Increases in five-year volume growth appear to be promising for at least 25% of our study population.

Results emphasize that response to nitrogen fertilizer, as applied, promises to be highly variable. Nonresponsive stands typically showed luxury N consumption in the absence of needle weight increase, i.e. a

"D" shift (Figure 2). This suggests the presence of other non-nutrient-limiting growth factors (Weetman and Fournier 1982). Lack of available moisture may preclude response to nitrogen fertilization in many situations throughout the Inland Empire. Many of the fertilizer trials are on shallow or droughty soils. Other factors like shrub-forb competition may also be important.

Levels of foliar nitrogen in control plots are usually low, often below or near the critical level of 1% reported for coastal Douglas-fir (Morrison 1974). Nonetheless, results suggest nitrogen fertilization may prove to be risky until models are developed to predict where other non-nitrogen limiting factors control Douglas-fir growth. Douglas-fir volume response to nitrogen fertilization will probably be substantial on at least 25% of the trials which occur over a very broad geographic distribution.

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